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2 - 12 MINUTE QUASI-PERIODIC VARIATIONS OF 50 - 1,000 KEV TRAPP--ETC(U)
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2 - 12 Minute Quasi-Periodic Variations of 50 - 1,000 keV Trapped Electron Fluxes Detected in the Afternoon Magnetosphere: 1. Physical Characteristics

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ABSTRACT

Physical properties of electron variations of periods in the range 2 - 12 minutes detected in the afternoon magnetosphere at synchronous altitudes by the University of Minnesota electron spectrometer on the ATS-1 are presented. We find that in the energy interval 50 keV to 1 meV, most of the electron variations are correlated with the intensity of the local magnetic field. This correlation exists down to a few minutes time scale. The pitch-angle analysis shows that the enhancement of fluxes occur primarily at large pitch-angles. We show in Part 2 of this series of papers that the electron variations can be accounted for by adiabatic causes.

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1. INTRODUCTION

Lin and Parks (1974) recently showed that trapped electron fluxes of energies 50 keV to 1 meV observed in the afternoon magnetosphere are periodic in space and/or in time. We have since used the high-resolution electron data to study further these periodic structures and in this article we report that these electron variations are (1) periodic in the range about 2 - 12 minutes (2) correlated with magnetic field variations (3) organized by the local magnetic field, and (4) pitch-angle dependent, with the variations larger at larger pitch-angles. These observations suggest that the electron variations are adiabatic. Part two of this series of paper by Lin et. al. (1975) derives the quantitative adiabatic expressions of particle flux variations in a model geomagnetic field perturbation. It will be shown that the observational features are consistent with effects arising from adiabatic modulation of trapped particle fluxes.

2. RESULTS

2.1 Time Variations of Electron Fluxes and Fourier Analysis:

Examples of quasi-periodic variations of equatorial electron fluxes are shown in Figures 1a, 1b, and 1c (see also examples in Lin and Parks (1974)). The data of February 7 and June 26, 1967 come from the period when the trapped fluxes were slowly decreasing while those of June 27, 1967 come from the period when the trapped fluxes were slowly recovering. All of these variations are observed in the afternoon magnetosphere. The probability of detecting the variations is maximum around 1600-1800 local hours. Note that the electron variations are independent of the energy. The electron variations are always detected simultaneously in all of the energy channels. The absence of time lags in the different

energy particles means that the variations must be produced locally near the satellite where they are detected.

The results of Fourier analysis of the electron data are shown in Figure 2. The frequency spectrums shown characterize the variations of both the electron and H-component magnetic field variations. The spectrum of June 26, 1967 further describes the behavior of protons of energies $\gtrsim$400 keV in addition to electron and the magnetic field. Figure 2 clearly shows the time variations are quasi-periodic. For the events that occurred in 1967, the range of periodicities detected was about 2 - 12 minutes. This conclusion is arrived at from both the Fourier analysis results and the simple determination of periods from the count-rate time profile (the latter method was used for segments of data that were too short for Fourier analysis).

Proton information was available for the June 26, 1967 event (Figure 1). Proton data, when Fourier analyzed, also show a significant peak around 0.24 $(\mathrm{min})^{-1}$, corresponding to the same peak observed in the electron data. However, the protons and the electrons did not vary in phase. Figure 3 shows the results of performing a coherence analysis between the two sets of data (top panel). While the peaks around 4.2 minute period were correlated, the electrons and the protons were out of phase by about 180°. The bottom panel shows the phase relation of electron and H component variations. The peaks at 4.2 and 12 minutes were correlated with a zero phase difference (note that the small phase seen around .24 $(\mathrm{min})^{-1}$ is not significant since it is caused by quantization error in the digitization process). The relationship of electron and the magnetic field shown here is typical of other events studied.

Since June 26, 1967 was the only period when the proton data were available, the results shown in Figure 3 only apply to this event.

2.1.1 Electron Flux Variations vs L:

As a first step toward identifying what caused the time variations in the electron fluxes, we plotted the electron fluxes as a function of L, defined by the relation $L=(o.31/B)^{1/3}$ where B is locally measured. Figure 4 shows such a plot for the variations detected on June 26 and 27, 1967. In this Figure, the flux values of 150-500 keV energy channel have been offset. The solid circles and triangles are electron data averaged over 6-minutes. This type of data describes adequately the type of variations previously studied by Lezniak and Winckler (1970), Erickson and Winckler (1973) and Bogott and Mozer (1973). Figure 4 indicates that the type of variations that occur with about 1 hour time scale is well-behaved in L and as previously noted the variations are adiabatic.

The open circles and triangles are electron data averaged over 25.6 seconds. The high-resolution data adequately describe the faster quasi-periodic structures of interest here. In this time scale, the electrons of energies 50-500 keV are still well-ordered in L. This means the electron variations in the 2-12 minute time scales are also adiabatic. This view is further supported by the pitch-angle analysis given below.

2.1.2 Pitch-angle Distribution and Variations:

Figure 5 shows typical examples of pitch-angle distributions obtained at the minimum and the peak of electron variations. First to note is that the pitch-angle distribution at the minimum flux is peaked toward smaller pitch-angles. At the peak, the distributions become more isotropic.

Thus, the increase of electron fluxes comes mainly from the large pitch-angle particles. It should be emphasized that although the example shown in the Figure comes from the variations detected around 0138 UT, the behavior shown is true for most of the variations studied and should not be construed to represent the characteristics of this particular variation.

The characteristics displayed in Figure 5 are consistent with adiabatic effects as will be demonstrated quantitatively in Part 2 by Lin et. al. (1975; see companion paper).

2.1.3 Frequency vs. B:

As already noted, the range of frequency observed is between about 1.3 to 8.3 mHz. An attempt was made to find out what factors influence the frequency of oscillation. We have examined the frequency as a function of the electron intensity, K_p, and the intensity of the magnetic field. The frequency is uncorrelated to K_p and the electron intensity. There is a weak suggestion that the frequency and the local magnetic field intensity might be correlated. Figure 6 shows a plot of the frequency as a function of $\langle|B|\rangle$, where $\langle|B|\rangle$ represents the average intensity of the magnetic field averaged over many cycles. For the events plotted, $\langle|B|\rangle$ varied between 40 and 130 gammas during which the variations were observed in the 1.3 to 8.3 mHz frequency interval.

In considering the origin of the oscillations, we note that the frequency characteristics of Alfven and drift waves are quite different. The former depends on $|\vec{B}|$ linearly because the Alfven velocity is proportional to $|\vec{B}|$, while the latter is inversely proportional to $|\vec{B}|$ (see Krall and Trivelpiece, 1973). Note that these wave properties are correct

only if the plasma density is assumed constant in the region of the wave oscillation. According to Figure 6, nothing definite can be said about these waves (see Barfield and McPherron (1972) for other properties of waves).

3. CONCLUSION

One of the main conclusions to be drawn from this study is that the variations of $\gtrsim$ 50 keV trapped electron fluxes that are frequently detected in the afternoon magnetosphere during substorms are predominantly due to adiabatic causes. Consequently, these energy electrons do not appear to take part directly in any instability mechanisms. Rather, the $\gtrsim$ 50 keV electron variations simply represent the response to magnetic field oscillations about the satellite ATS-1. The adiabatic variations are produced in situ and on the average the modulation of the trapped electron population does not alter the average energies of the trapped radiation.

The sources of the waves need not be local. With regard to the mechanisms that might be involved for these waves, we made an attempt to evaluate whether a drift-mode instability was involved (see Figure 6). In view of absence of strong 1/B dependence of the frequency of oscillation, nothing definite can be said about this instability mechanism. We wish to note however that the data of Baxter and LeQuey (1973) and Lanzerotti et. al., 1969) support the view that drift-mode instability might be operating in the magnetosphere. From our analysis of the electron data, the only evidence we have is the electron-proton anticorrelation observed in the June 26, 1967 oscillations.

In conclusion, we wish to note that the electron oscillation events observed at the ATS-1 for electron energies $\gtrsim$50 keV are adiabatic as indicated in this paper. However, on several occasions electron modulations were observed in the total absence of magnetic field oscillations

(not shown). The cause of these non-adiabatic oscillations is not known but one possibility is that they are related to electrostatic waves. Properties of these non-adiabatic structures will be further studied and reported in another paper.

ACKNOWLEDGEMENT

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FIGURE CAPTIONS

Figure 1a: The electron count-rate time profile detected on the ATS-1 and the magnetic field data in three components. The electron data are 25.6 second averages and the magnetic field are 2.5 second averages (courtesy of UCLA).

Figure 1b: Same as Figure 1a except that proton data from Bell Laboratory detector are included. All data are 1-minute averages.

Figure 1c: Same as Figure 1a. Data are 1-minute averages.

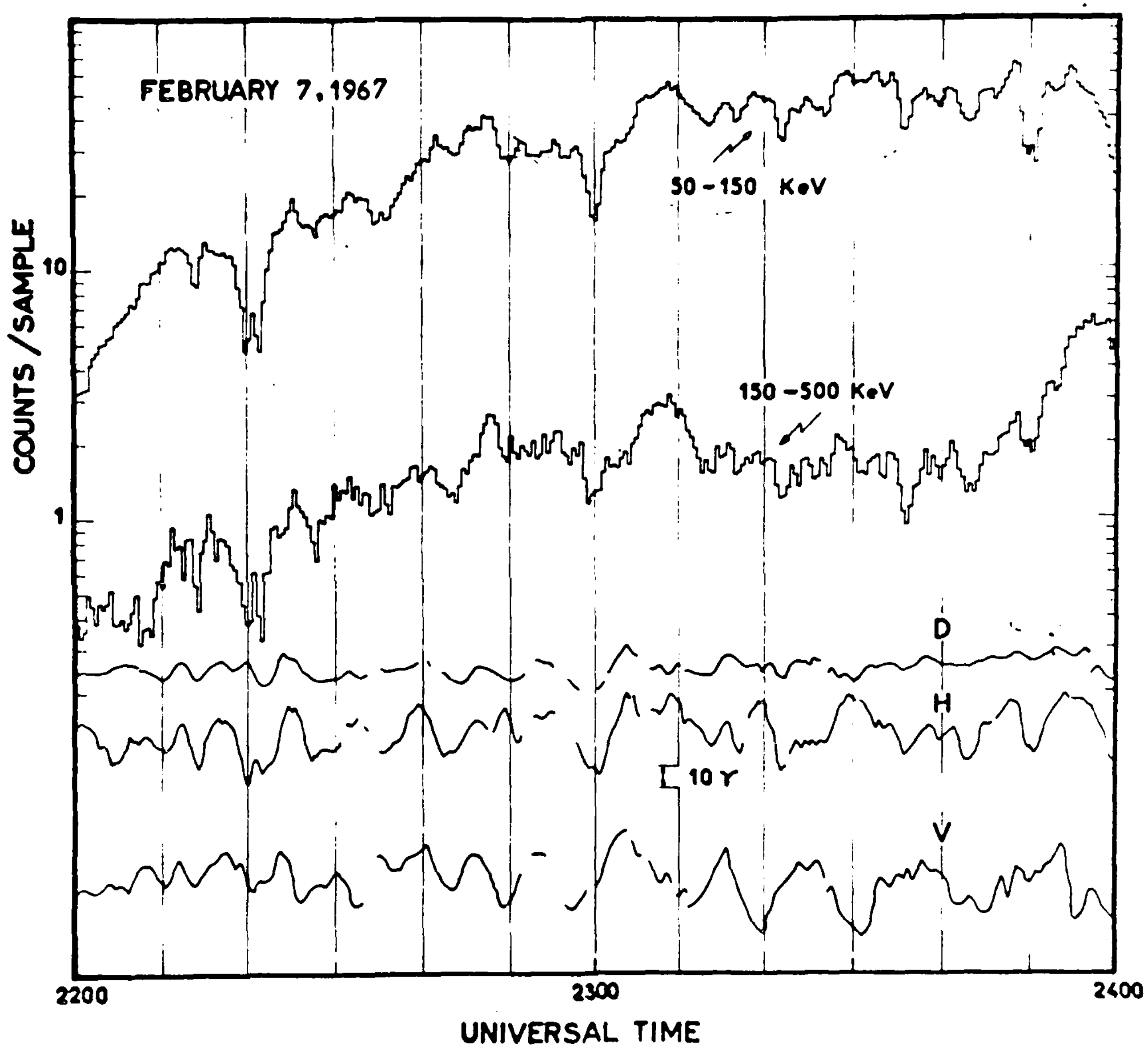
Figure 2: Power spectral analyses results of the three events shown in Figure 1.

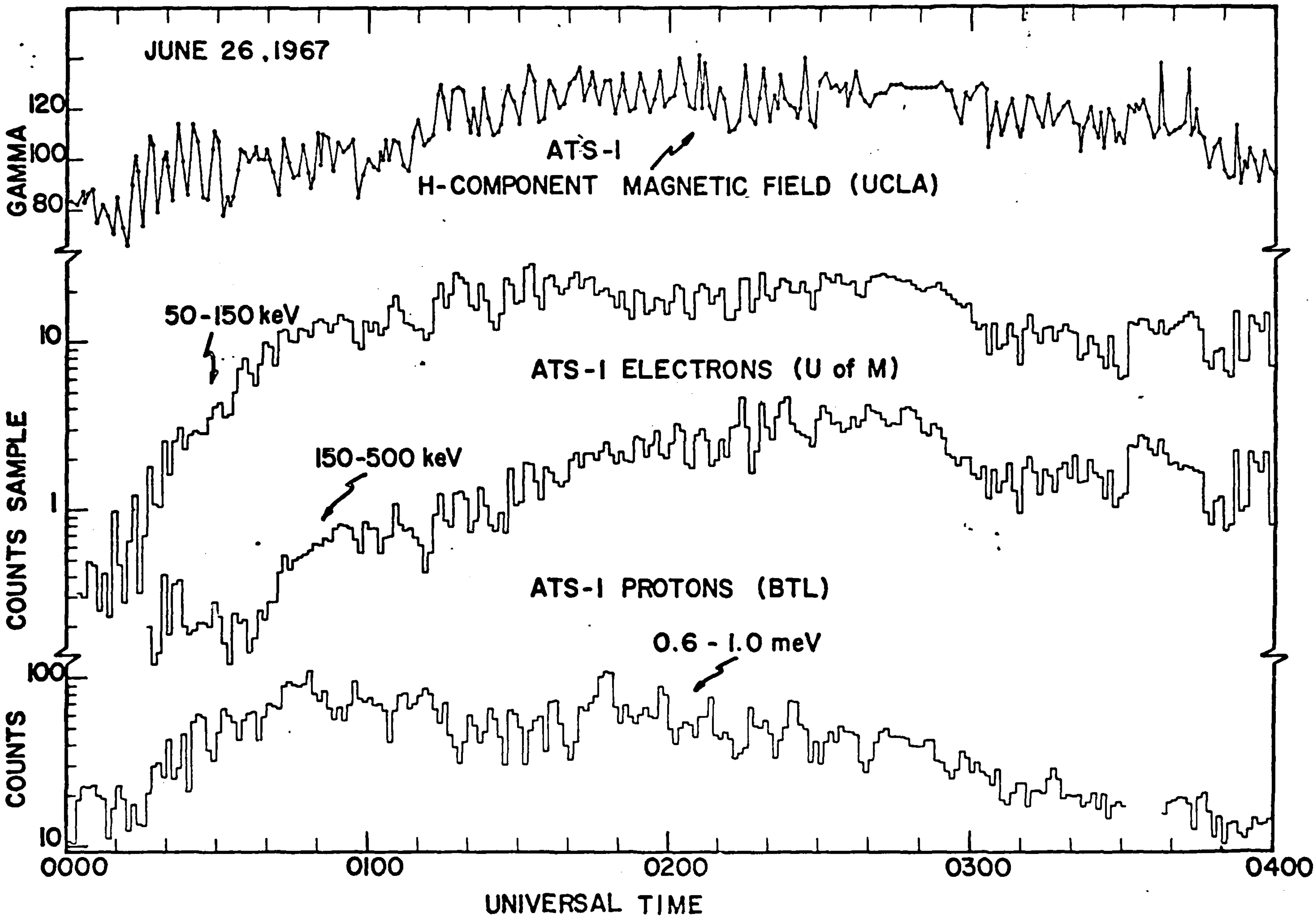
Figure 3: Coherence analysis between electrons and protons and electrons and the magnetic field for the June 26, 1967 event.

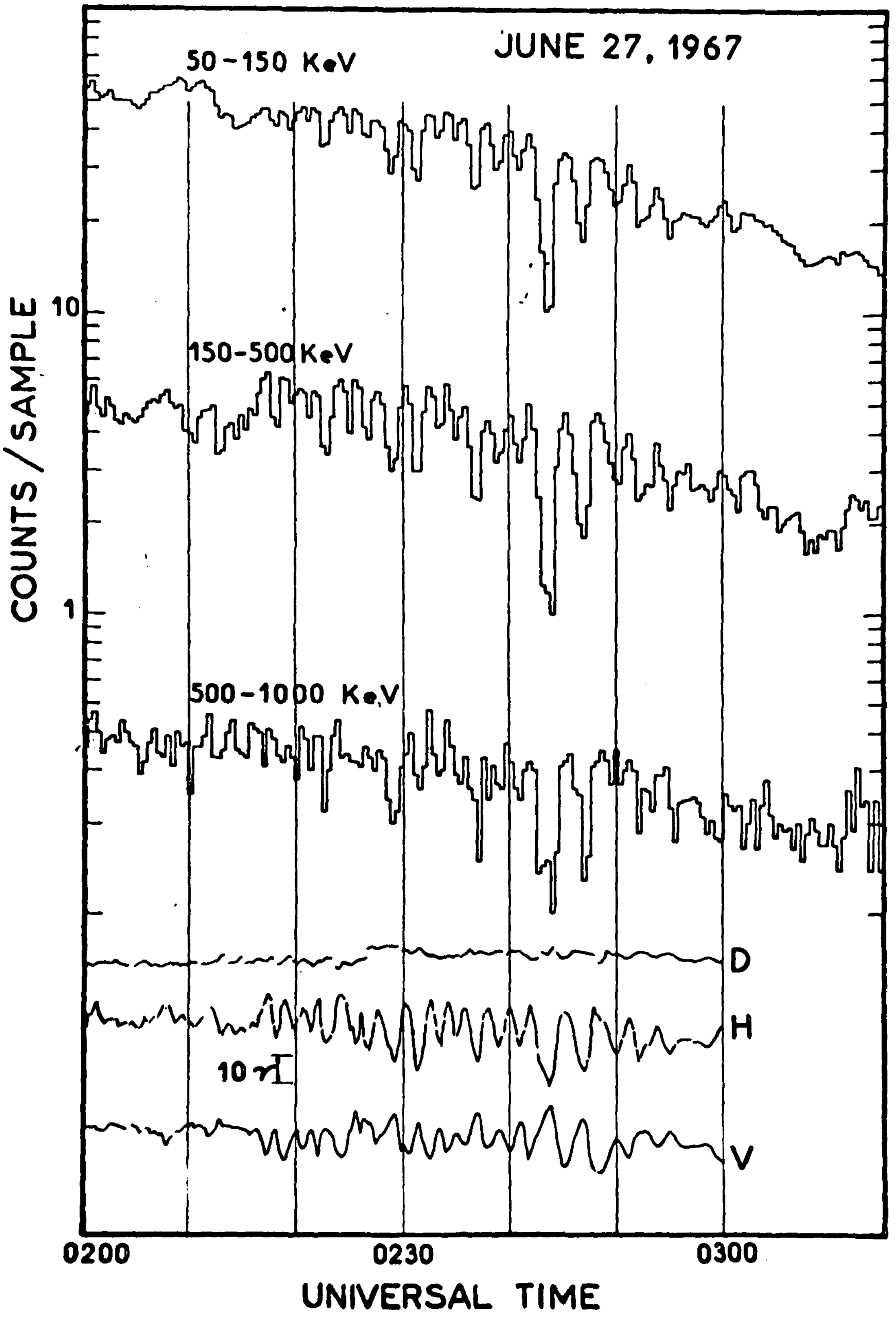
Figure 4: Electron flux vs. L parameter. Open circles and triangles are data that were averaged over 6-minutes. Closed circles and triangles are 25.6 second averaged data. Note that the fluxes are well-organized by L.

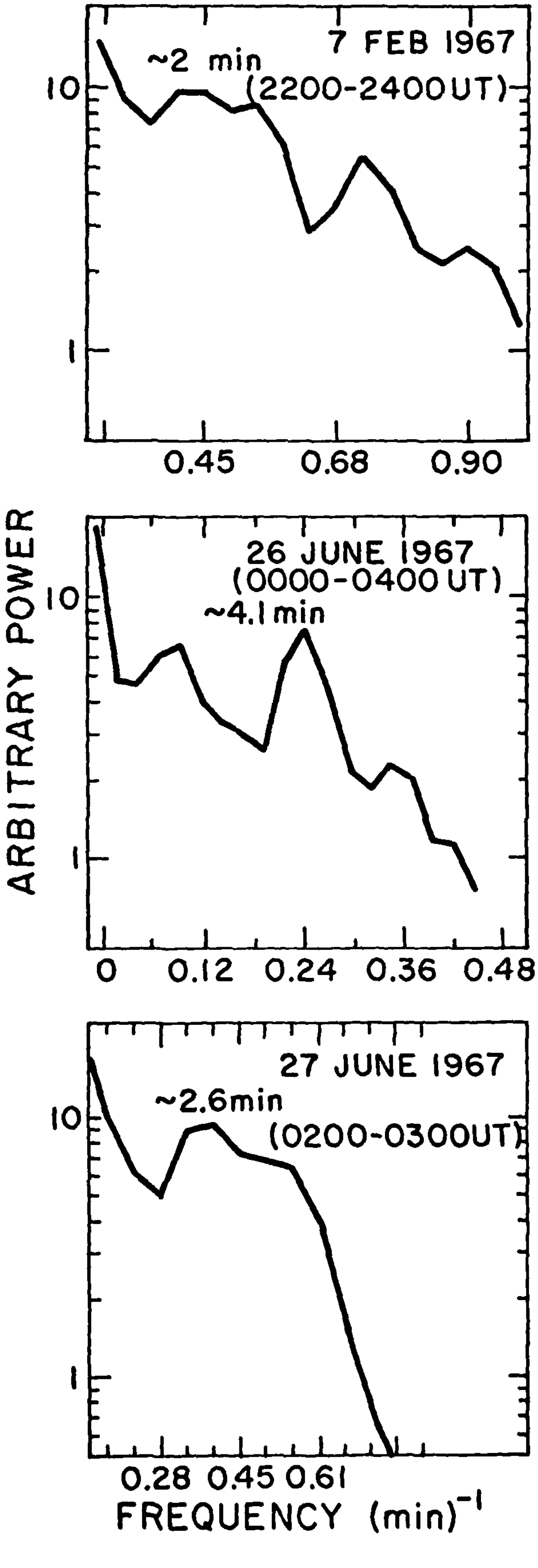
Figure 5: Behavior of pitch-angle distribution during oscillations. Large increases are observed at high pitch-angles.

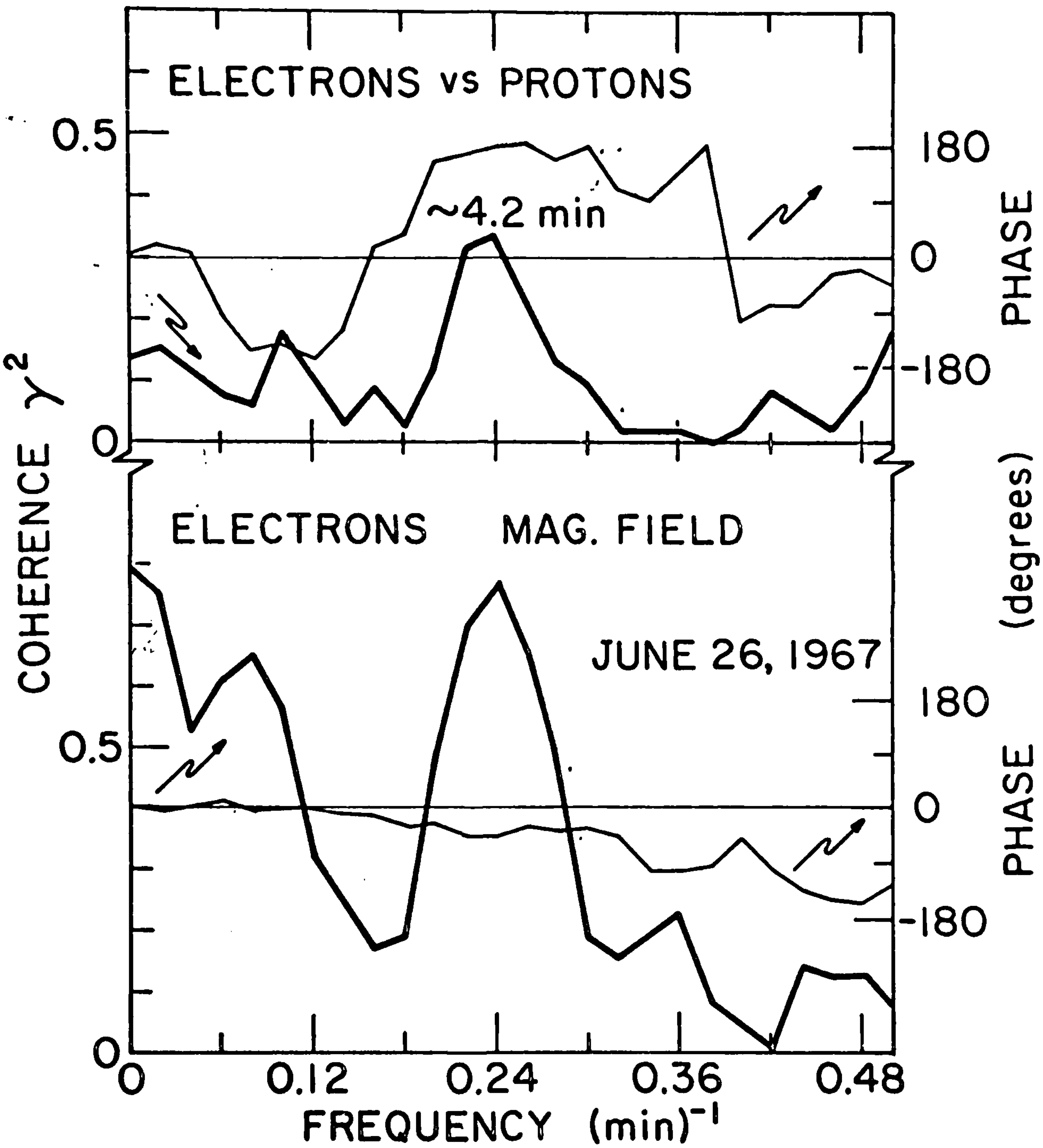
Figure 6: Frequency of oscillation vs. magnetic field intensity averaged over many cycles of the oscillations. The dashed line represents f = 1/B curve. These events were all detected in 1967.

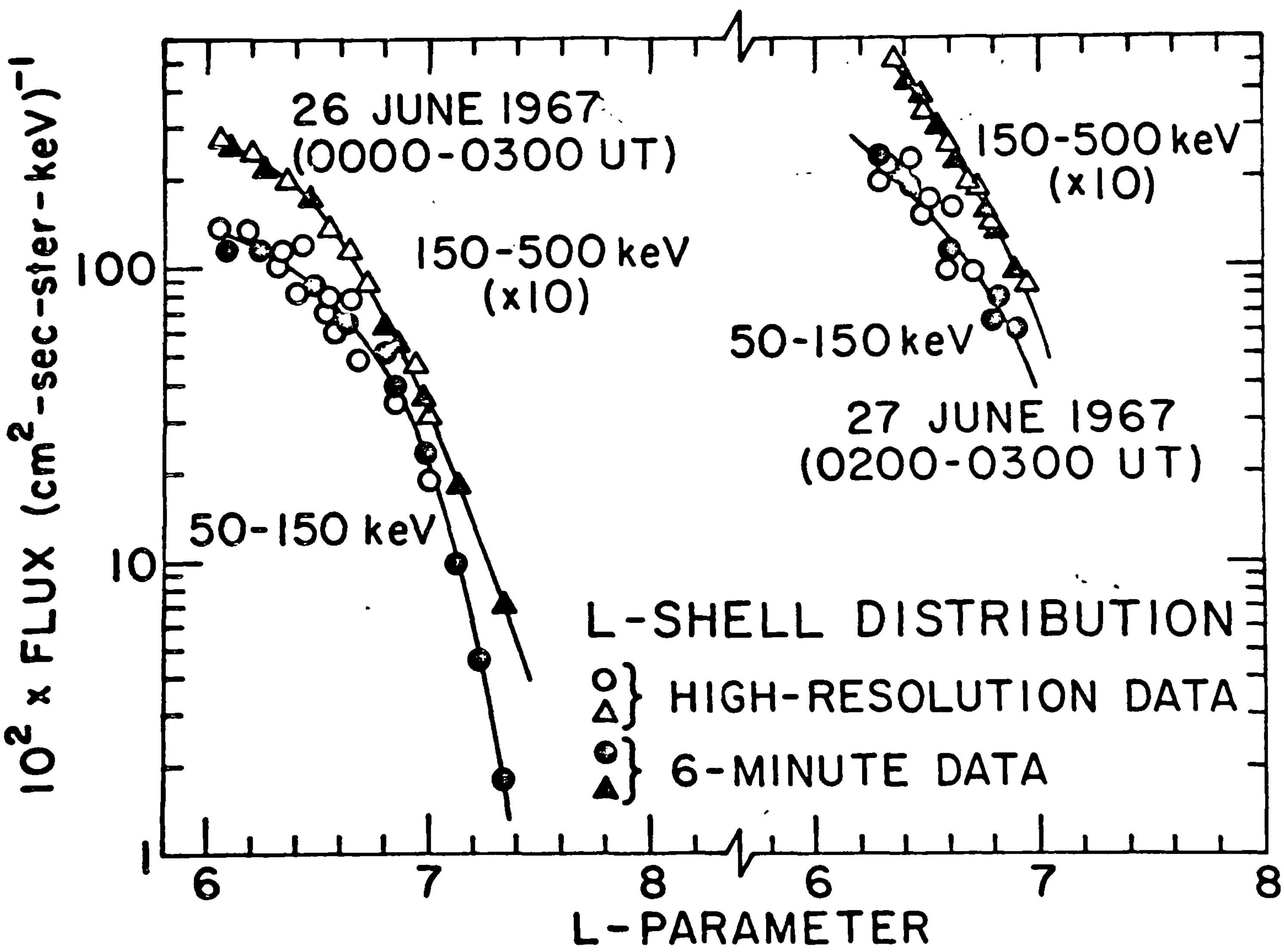

FEBRUARY 7, 1967
50 - 150 KeV
150 - 500 KeV
COUNTS / SAMPLE
10
1
D
H
10 γ
V
2200
2300
2400
UNIVERSAL TIME

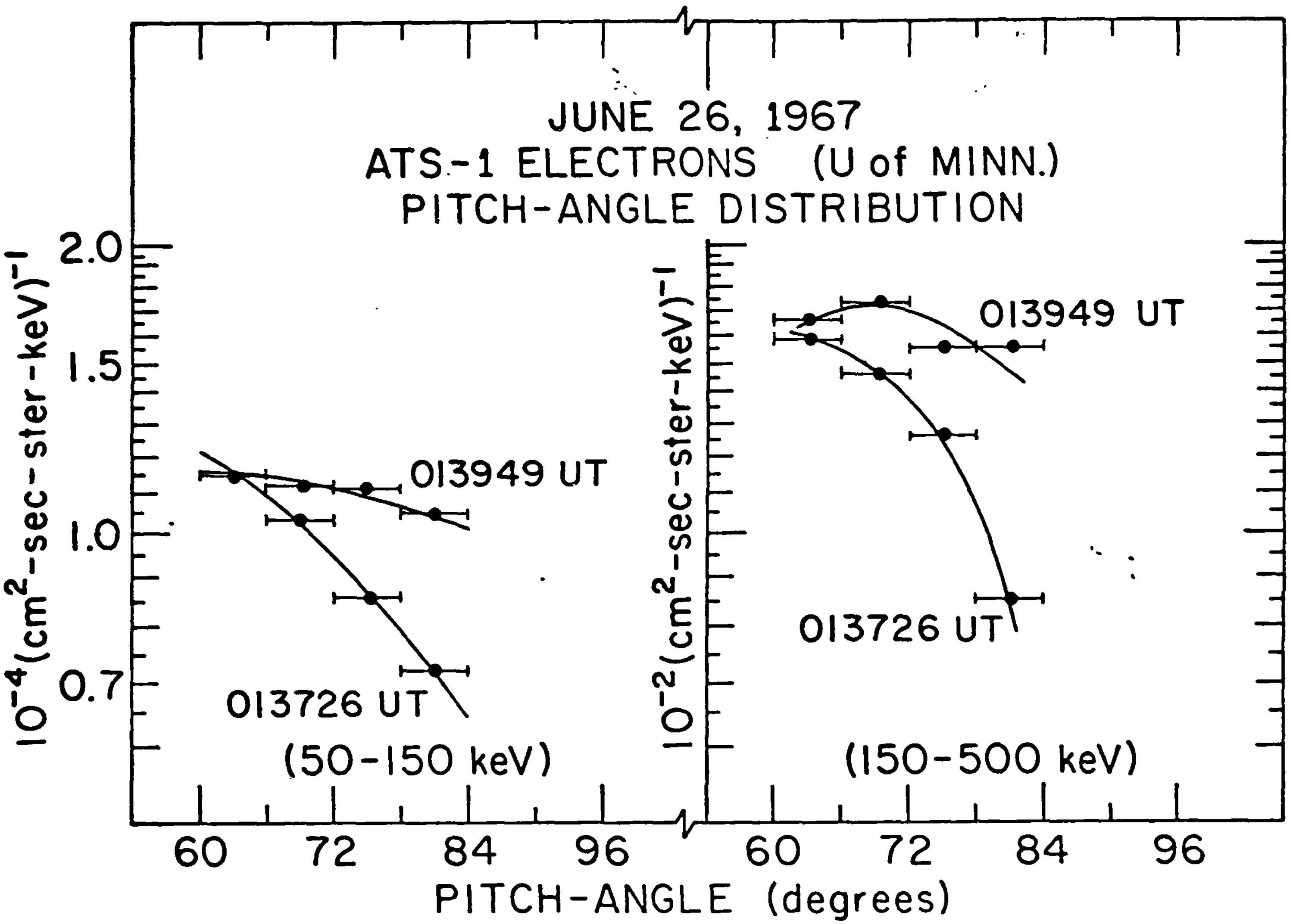

JUNE 26, 1967
GAMMA
120
100
80
ATS-1
H-COMPONENT MAGNETIC FIELD (UCLA)
COUNTS SAMPLE
10
1
50-150 keV
ATS-1 ELECTRONS (U of M)
150-500 keV
ATS-1 PROTONS (BTL)
0.6 - 1.0 meV
COUNTS
100
10
0000
0100
0200
0300
0400
UNIVERSAL TIME


JUNE 27, 1967
50-150 KeV
150-500 KeV
500-1000 KeV
COUNTS/SAMPLE
10
1
D
H
V
10 γ
0200
0230
0300
UNIVERSAL TIME

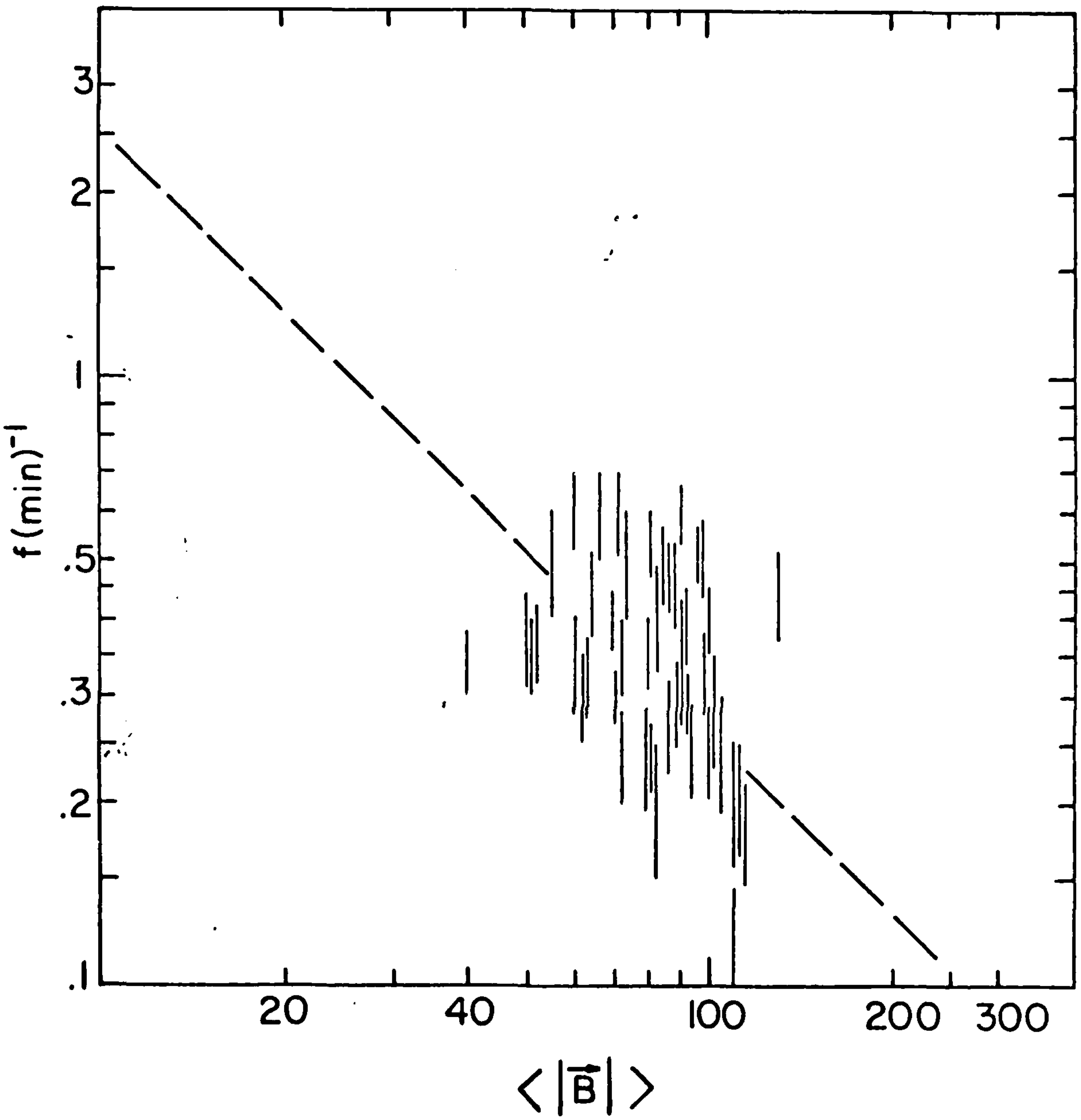

7 FEB 1967
(2200-2400UT)
~2 min
26 JUNE 1967
(0000-0400 UT)
~4.1 min
27 JUNE 1967
(0200-0300UT)
~2.6min
ARBITRARY POWER
10
1
0.45 0.68 0.90
0 0.12 0.24 0.36 0.48
0.28 0.45 0.61
FREQUENCY (min)⁻¹


ELECTRONS vs PROTONS
~4.2 min
ELECTRONS MAG. FIELD
JUNE 26, 1967
COHERENCE γ^2
PHASE (degrees)
0.5
0
180
-180
0.12
0.24
0.36
0.48
FREQUENCY $(min)^{-1}$


26 JUNE 1967
(0000-0300 UT)
150-500 keV
(x10)
50-150 keV
150-500 keV
(x10)
50-150 keV
27 JUNE 1967
(0200-0300 UT)
L-SHELL DISTRIBUTION
HIGH-RESOLUTION DATA
6-MINUTE DATA
10^2 x FLUX $(cm^2\text{-sec-ster-keV})^{-1}$
L-PARAMETER



JUNE 26, 1967
ATS-1 ELECTRONS (U of MINN.)
PITCH-ANGLE DISTRIBUTION
2.0
1.5
1.0
0.7
$10^{-4}(cm^2\text{-sec-ster-keV})^{-1}$
013949 UT
013726 UT
(50-150 keV)
$10^{-2}(cm^2\text{-sec-ster-keV})^{-1}$
013949 UT
013726 UT
(150-500 keV)
60
72
84
96
60
72
84
96
PITCH-ANGLE (degrees)



3
2
1
.5
.3
.2
.1
f (min)$^{-1}$
20
40
100
200
300
$\langle |\vec{B}| \rangle$